Evaluation of two techniques for the utilization of logging residues: Organic mulch for abandoned road revegetation and accelerated decomposition in small chipped piles

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An Evaluation of Two Techniques for the Utilization of Logging Residues:

Organic Mulch for Abandoned Road Revegetation

and Accelerated Decomposition in Small Chipped Piles

by Kari Bradley

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Date
Logging residues are an underutilized forest resource in the Intermountain West. The foliage and branches remaining after harvest constitute substantial pools of organic matter in that semi-arid region and thus could be used to enhance productivity on a variety of locations. However, logging residues are generally disposed of through prescribed fire in order to reduce wildfire hazards. Few beneficial applications have been demonstrated. A study was designed to evaluate two techniques for the utilization of logging residues.

At two sites in western Montana, surface applications of lopped and chipped slash were compared with other commonly used road restoration methods (scarification, fertilization, topsoiling) as to their capacity to support seeded grass and improve soil physical properties. Scarification and lopped slash mulch significantly improved germination of seeded species relative to controls 6 weeks after preparation. After 12 weeks, dry weight yields of seeded species were improved on lopped slash/fertilizer and scarified treatments at both sites. The combination of scarification, lopped slash mulch, and fertilizer produced more aboveground biomass and mature seedheads than any other treatment. Invasion by weedy species was generally discouraged by scarification and unaffected by mulching. After 14+ weeks scarification had improved penetrability and infiltration rates at both sites and bulk densities at one site. Mulching with lopped slash maintained lower bulk densities on scarified plots by protecting soils from sealing with eroded fine particles. The results of this study indicate that the use of logging slash in conjunction with scarification is warranted in the rehabilitation of abandoned roads.

A second experiment served as a preliminary investigation into whether treatment of slash with composting techniques can significantly enhance its rate of decomposition. Douglas-fir undergrowth from a commercial thinning was separated into stemwood and foliage/fine wood, chipped, piled, mixed with local soil, and left to decompose. Treatments included: a) equal parts stem and foliage, b) 2 parts stem and 1 part foliage, c) 2 parts stem and 1 part foliage + cow manure, and d) unchipped slash. After 13 months, all chipped treatments appeared much more decomposed due to conservation of moisture and increased surface area for fungal colonization. Decomposed slash was comparable to mineral soil as a growth medium in terms of germination rates and biomass yields in a greenhouse experiment.
Preface

Many thanks to all the people who contributed to this study: Don Bedunah, Larry Cole, Kurt Coonio, Skip Hegman, Larry Laing, Rosemary Leach, Frank Maas, Ken Miller, and Kevin Ryan.

Extra special thanks to Tom DeLuca for all his encouragement and support.

This thesis is dedicated to Gabrielle and Simon: love is the framework that gives our work meaning.
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CHAPTER 1: INTRODUCTION

Logging residues are an underutilized forest resource in the Intermountain West. The foliage and nonmerchantable wood remaining after timber harvest constitute potentially valuable pools of reduced carbon and nutrients in that region marked by dry climate and low organic matter accumulation. Applications of organic matter to soils can improve water relations, fertility, aeration, and microbial activities (see Stevenson, 1986 and Hudson, 1994 for recent reviews). Thus logging residues could be used to enhance productivity on a variety of locations, including the stands from which they came and severely degraded sites. However, few practical applications of this material have been demonstrated and little is known about its potential effects on soils or plant growth.

Mature forests of Montana and Idaho contain an estimated 22-57 metric tons of leaves and branches (less than 7.5 cm in diameter) per hectare (Benson and Schlieter, 1980). Logging operations offer an excellent opportunity to access this resource, because they systematically separate needles and fine wood from stemwood. However, the residues of logging have traditionally been perceived as valueless byproducts requiring disposal. Land managers in the northern Rocky Mountains customarily rely on prescribed fire to reduce the wildfire hazard associated with dried logging slash (Fischer and Clayton, 1983; Smith, 1986; Graham et al., 1994). With little other benefit, such management of slash can be expensive. Both human and mechanical resources are required to arrange and burn logging residues. The timing of prescribed burning must be carefully planned in accordance with atmospheric and moisture conditions. Smoke and unburned particles make slash burning a significant source of air
pollution and when slash fires burn out of control, additional labor and materials are required for fire fighting (Ruth and Harris, 1975).

Slash burning also has environmental impacts. Despite increasing the short term availability of some plant nutrients, combustion of organic matter transports substantial amounts of organic C, N, P, Ca, Mg, and K off site in the forms of gaseous oxides and fly ash (Harwood and Jackson, 1975; Feller and Kimmins, 1984). For nutrient poor sites, indiscriminate slash burning in conjunction with stem harvest may result in deleterious reductions of organic matter, nutrients, and ultimately long-term productivity (Ruth and Harris, 1975; Kimmins, 1987). Decaying wood are important sites for the formation of ectomycorrhizal root infections and N₂ fixation by freeliving bacteria (Graham et al., 1994); slash burning may inhibit these processes. Finally, high intensity fires, such as those associated with jackpot burns, can result in temporarily hydrophobic soils, thereby potentially inducing plant water stress, accelerated erosion, and additional nutrient losses to streams and groundwater (Lewis, 1974; Henderson and Golding, 1983; Feller and Kimmins, 1984).

Although soil and surface organic matter is limited in many parts of the Intermountain West, management techniques that make use of logging slash have received little attention. This paper summarizes a study designed to evaluate two techniques for the utilization of logging residues. The purpose of the first part was to study the usefulness of logging slash as a mulch in revegetating abandoned roads in dry climates; surface applications of slash were compared with other commonly used road restoration methods as to their capacity to support seeded vegetation and improve soil physical properties. The second component of this thesis serves as a preliminary investigation into whether treatment of slash with composting techniques can
significantly enhance its rate of decomposition; quicker conversion of logging residues into humified material suitable for land spreading would presumably greatly enhance its utility and economic value. Ultimately, this study is intended to explore the possibility of improved management of this often neglected forest resource.

The following chapter summarizes much of the published knowledge in the areas of road restoration and forest litter and slash decomposition; it also provides the objectives of this study. The experimental design is then presented including the details of study sites, materials, and methods in Chapter 3. Chapter 4 presents the results of the study and Chapter 5 is an evaluation of them. Practical considerations including limitations of these applications are discussed.
CHAPTER 2: PROBLEM BACKGROUND

Literature Review

Road Revegetation

Roads adversely impact a variety of soil, water, and environmental properties. Numerous researchers have shown that forest roads increase surface runoff, erosion, and sediment delivery to streams and thereby deteriorate water quality and fish habitat. While road removal and revegetation projects are an increasingly popular means of addressing these impacts, the effectiveness of various techniques of road rehabilitation is poorly understood. In particular, the use of organic mulches in road revegetation projects in semiarid regions has received very little scholarly attention.

Stresses on a soil in excess of resistive forces (i.e. soil strength) cause deformation or displacement; the vertical stresses resulting from road construction, maintenance, and use result in severe soil compaction (Alexander and Poff, 1985). Soil compaction is associated with the expulsion of air, reductions in overall porosity, and in turn, increases in bulk density (Graecen and Sands, 1980). In addition, compaction converts macropores to micropores which limits gas diffusion and water movement in soils (Taylor, 1949; Graecen and Sands, 1980; Cullen et al., 1991). Physical impacts to soil combine to hinder the activities and growth of microbial and plant populations (Zimmerman and Kardos, 1961; Froelich, 1979; Graecen and Sands, 1980). Viehmeyer and Hendrickson (1948) identified a soil bulk density threshold of 1.9 g cm$^{-3}$ above which root penetration was impossible. A number of investigators have reported reductions in seedling survival and growth, post-seedling growth, and overall stand yield associated with severe compaction (Zimmerman and Kardos, 1961; Foil and Ralston, 1967; Hatchell et al., 1970;
Wert and Thomas, 1981). The specific effect of compaction on plant growth is related to soil texture and strength, per cent soil organic matter, the specific change in bulk density, and species tolerances (Viehmeyer and Hendrickson, 1948; Graecen and Sands, 1980; Alexander and Poff, 1985).

Water comes into contact with road surfaces via precipitation, snowmelt, surface runoff, or interception of subsurface flows (Brooks et al., 1991; Montgomery, 1994). However, water movement into and within road prisms is characteristically slow because of severe compaction and the lack of transpiring plants (Moll, 1996). Saturated hydraulic conductivities of roads are typically less than 4 mm hr$^{-1}$ and infiltration capacities are correspondingly low (Luce, 1997). As a result, roads create and concentrate overland flow far in excess of undisturbed soils (Hatchell et al., 1970; Harr et al., 1975). At the same time, roads reduce soil strength by removing vegetative cover and root systems, exposing mineral soil, undercutting slopes, sidecasting cutslope material, and altering drainage (Brooks et al., 1991).

Surface and subsurface flows in excess of resistive forces result in detachment and transport of soil; roads greatly enhance the potential for both surface erosion and soil mass movement (Beschta, 1978; Montgomery, 1994). Numerous studies have confirmed the severe erodability of forest roads. Erosion rates from forest roads in the Klamath Mountains of southwest Oregon were 100 times those of undisturbed soils (Amaranthus et al, 1985). The failure rate of roads in the Canyon Creek watershed of northwestern Washington was 110 times greater than that of unroaded areas over a 15 year period (Harr and Nichols, 1993).

Such increases in upland erosion typically result in elevated delivery of sediment to streams. Heavily used roads generated 130 times as much sediment as other forest surfaces in a
western Washington watershed (Reid and Dunne, 1984). Increases in sediment yields associated with failures on upland roads in an Oregon watershed lasted 5-8 years (Beschta, 1978). Furthermore, roads have been linked to increases in sediment recruitment from instream sources; road systems expand the effective channel networks of watersheds and thus can impact flow regimes and bank stability (Harr et al., 1975; Jones and Grant, 1996).

The erosion associated with roads adversely affects water quality of streams down slope; fish habitat in particular is threatened by sediments generated from roads. Fine particles fill in spaces between gravels and smother the eggs and embryos of several species of salmon (Duncan and Ward, 1985). Larger sediments fill pools used by juveniles and mature fish (Harr and Nichols, 1993). Roads have been implicated in severe populations declines in dozens of species of anadromous Pacific salmonoids (Oncorhynchus spp.) (Nehlsen et al., 1991).

Soil compaction is alleviated through wetting/drying and freeze/thaw cycles as well as the activities of plant roots and soil organisms (Alexander and Poff, 1985). Although recovery tends to be somewhat quicker in regions with severe winters, soil bulk densities decrease slowly via natural processes (Hatchell et al., 1970; Alexander and Poff, 1985). Even moderately compacted soils in the northwestern U.S. may require decades to initiate recovery (Graecen and Sands, 1980; Froehlich et al., 1985). Without active rehabilitation, the revegetation of roads tends to proceed slowly and may be limited to occupation by weedy species capable of tolerating droughty soils.

In order to satisfy public demand and ameliorate the adverse environmental effects associated with roads, public land managers are increasingly electing to restore roads that are no longer needed. Currently many timber sale plans specify the removal of temporary or “roll up”
roads following harvest in order to minimize watershed impacts. Priorities of road closure and obliteration projects include restricting access, restoring natural drainage patterns, minimizing erosion, increasing hillslope stability, and revegetating disturbed areas (Moll, 1996). Revegetation of roaded surfaces is particularly important because of its influence on water and soil movement and should be considered a minimum objective of any road reclamation project.

Approaches to forest road reclamation are site-specific yet generally machine intensive (Moll, 1996). The compacted soils are virtually always mechanically scarified using rock rippers or subsoilers in order to create drainage pathways, reduce soil strength, and ultimately promote revegetation (Cotts et al., 1991). Many Forest Service roads are fully recontoured using excavators in order to recreate the original topography and improve infiltration capacity (McNabb, 1994; Moll, 1996). Mulches, silt fences, check dams, biodegradable erosion mats, and sediment basins may be employed to control sheet and rill erosion (Maynard and Hill, 1992; Moll, 1996). Rock buttresses, timber cribs, and a variety of artificial materials are used to stabilize hill slopes and avoid mass wasting (Moll, 1996). Scarified roads are usually seeded with mixtures of either native or nonnative grasses and forbs in conjunction with inorganic fertilizers (especially N and P) (Moll, 1996). Seed and fertilizer applications are often repeated several months after initial treatment (S. Hegman, J. Simon, personal communications).

Currently little is known regarding the effectiveness of these treatments or others in restoring road sites. Scarification has been shown to improve bulk density and infiltration rates on some sites but results are not consistent (Cotts et al., 1991; Luce, 1997). Tillage of dry soils to depths of 50 cm or more using winged subsoilers are especially effective in reducing bulk densities of temporary logging roads (McNabb, 1994). Soil settling and surface sealing have
been shown to diminish the improvements to soil physical properties 1-3 rainfall events after scarification (McNabb, 1994; Luce, 1997). Scarification does appear to consistently improve germination and growth of seeded plants by relieving soil strength and increasing soil moisture (Wright and Blaser, 1981; Cotts et al., 1991; Ashby, 1997).

Cotts et al. (1991) observed greater plant cover in plots seeded with indigenous (locally gathered) plant materials than in those which received commercially-supplied native plant seed. Application of 10-10-10 fertilizer improved plant vigor on abandoned roads and skid trails in Connecticut during the growing season after treatment but its effect was not discernible the following year (Maynard and Hill, 1992). The benefits of inorganic fertilizers to plant growth on roads in water limited environments have not been clearly established (Wright and Blaser, 1981; Cotts et al., 1991).

Dressing with topsoil is often recommended by state transportation departments for revegetating road cuts and highway medians (Wright and Blaser, 1981). Topsoil is defined as roughly the upper 20 cm of a soil profile and thus is characterized by relatively high organic matter content except in forest soils (Schuman et al., 1985). Both forage production and water infiltration capacity improved with applications of 40+ cm of topsoil on mine spoils in Wyoming (Schuman et al., 1985). As little as 5 cm of topsoil has been shown to promote revegetation and improve infiltration as well as other physical properties on abandoned roads in arid regions (Cotts et al., 1991). Potential shortcomings include weed seed contamination, low fertility in stored topsoil, and prohibitive costs including purchase, transportation, and spreading (Wright and Blaser, 1981).
Due to the intensive use of machinery and materials, road restoration is typically expensive. Costs for full obliteration including an excavator, grass seed, fertilizer, and labor in northwest Washington averaged $3000-16500 per mile (Harr and Nichols, 1993). Similarly, on an Idaho National Forest current obliteration costs range from $3,000-20,000 per mile depending on the extent of rehabilitation and location (J. Simon, personal communication). The use of excavators, topsoil, and native seed would presumably most strain budgets. Given the increasingly prevalent objective of reclaiming forest roads and a lack of capital available for such projects, cost-efficient techniques are clearly needed.

Applications of organic mulches (i.e. nonliving materials placed on the soil surface to enhance plant growth) have a number of potential benefits for the reclamation of forest roads. By intercepting solar radiation, mulches typically reduce soil temperatures and evaporative demand and thereby increase plant available water in soils (Hopkins, 1954; Packer and Aldon, 1978; McGinnies, 1987); these effects make mulch especially valuable in rehabilitating arid and semi-arid sites. The modifications in radiation and moisture provided by mulches may enhance the competitive abilities of native species relative to weedy species (Maynard and Hill, 1992). Organic mulch applications return organic matter to degraded sites; the eventual incorporation of humus into a degraded soil has numerous benefits including improvements in plant available water, soil structure and porosity, bulk density, infiltration rate, nutrient status, and microbial activity (Stevenson, 1986; Hudson, 1994). Finally, surface applications protect soil from rainfall impact and particle detachment and transport (Maynard and Hill, 1992; Luce, 1997). The physical protection of mulching is particularly important because scarification exposes soils to rain drop impact and accelerated erosion (Moll, 1996).
With respect to road rehabilitation in the west, organic mulch applications have not been properly studied and few relevant studies can be found in the literature. Hay mulch retarded biomass production through 6 months and had no effect after 16 months in a study of forest road and skid trail revegetation in Connecticut, a non moisture-limited environment (Maynard and Hill, 1992). Cotts et al. (1991) found no improvement in plant community development after 2 years due to mulching; in that study aspen and red cedar woodchips were applied at relatively heavy rates (45 Mg ha\(^{-1}\)) which may have hindered soil moisture recharge. Mulching with composted biosolids has proven successful in restoring vegetation and mitigating erosion from forest roads in the Cascade Mountains east of Seattle but no formal study has yet been completed (Schindler, 1997).

**Decomposition of Forest Residues**

Applications of fresh ligneous materials to soils result in severe N immobilization and generally are toxic to plants (N'Dayegamiye and Isfan, 1991). Consequently, although logging residues constitute substantial pools of organic matter, they are unsuitable as a soil amendment in their raw form. By reducing the C:N ratio of substrates and converting them to humus, composting can generate an amendment that is beneficial to soils and plant growth. While the natural decomposition of forest litter has been extensively studied, relatively little is known about the artificial enhancement of that process.

Logging residues include leaves, bark, reproductive features, branch and stemwood of trees and shrubs. The chemical components of organic residues vary in an array of characteristics. They range in size from small 5-C sugars to cellulose (chains of 2000 to 15,000 sugars) to extremely long polymers such as lignin (Aber and Melillo, 1991). In terms of chemical complexity, the substrates
found in forest litter include simple sugars, saturated hydrocarbons (e.g. cutin) and amorphic polyphenolics (e.g. tannins) among many others (Waring and Schlesinger, 1985). Cellulose is a primary constituent of most vegetation (Aber and Melillo, 1991); it makes up 40-50% of the wood, foliage, and roots of many eastern conifers (McClaugherty, 1985). Lignin, characterized as insoluble, amorphous polymers of aromatic rings and other organic compounds, comprises up to 40% of some plant materials in forest detritus (Crawford, 1981; McClaugherty, 1985). The stem and branch wood of older trees is more lignified than that of younger ones (Waring and Schlesinger, 1985).

Decomposition of litter is carried out by a variety of organisms on a variety of scales. Macro- and mesofauna (including termites, ants, and earthworms) physically fragment litter in metabolizing carbon-containing compounds for energy. This larger scale degradation can account for the respiration of up to 7% of litter mass (Witkamp and Ausmus, 1976). Importantly, the activities of soil animals rupture resistant surfaces (e.g. cutin), increase surface area for microbial attack, and thus greatly increase overall decomposition rates (Kimmins, 1987).

Soil bacteria and fungi are responsible for the bulk of organic litter decomposition (Stevenson, 1986; Crawford, 1991). These organisms attack plant tissues via surface colonization or cell wall penetration (Aber and Melillo, 1991). They produce a variety of enzymes (e.g. cellulase) to cleave chemical bonds, and thereby yield energy, nutrients and/or more simple molecules for further metabolism (Aber and Melillo, 1991). Soil microbial decomposers work in concert to convert plant litter to CO₂, water, inorganic ions, humus and their own biomass (Stevenson, 1986). Due to greater tolerance to acidic conditions, fungi (especially white-rot species) are the primary decomposers of lignin in forests (Crawford, 1991).
Scientists have utilized a number of different techniques in order to estimate rates of litter decomposition. A prominent method involves incubating a particular substrate in the laboratory or under field conditions; the percent of mass remaining after some period of time is used as a measure of the rate of decay. A turnover coefficient \((k)\) is calculated as the proportion of substrate that is decomposed per unit time (Olson, 1963). Using the \(k\) coefficient, Olson (1963) devised an exponential function to describe decay rates:

\[
\% \text{ original mass remaining} = e^{-kt}
\]

where \(k\) = a litter-specific coefficient and \(t\) = time. An alternative methodology uses CO\(_2\) evolution as an index for decomposition rates; this technique is expensive and unreliable due to the inability to separate soil and root respiration (Waring and Schlesinger, 1985).

Values of \(k\) are ascribed to both specific litter types and particular ecosystems with regards to the rates of decomposition; high values (>1.0) are associated with regions of rapid decomposition (such as the tropics) as well as easily degraded substrates (such as deciduous leaves). Mean residence time (MRT), the amount of time required for complete decay of a substrate, is calculated as \(1/k\) (Waring and Schlesinger, 1985). Table 1 summarizes a number of the reported values of \(k\) and MRT by biome and/or vegetation type for the northern Rockies. It must be noted that ascribing a single, constant coefficient to decomposition rates is a drastic simplification because litter (on both the micro- and macrosite scale) is composed of various proportions of different compounds whose decay rates vary in time (Aber and Melillo, 1991). Ultimately the \(k\) coefficient is simply a useful tool for simplifying and modeling extremely complex systems.

| Table 1. Decomposition coefficients (\(k\)) and mean residence times (MRT) of forest litter for various regions and forest or vegetation types in the Northern Rocky Mountains |
The processes and rates of degradation are regulated by a combination of biotic and abiotic factors. On the continental and global scales, macroclimate has been shown to be the most influential variable (Meentemeyer, 1978). This can be explained by the direct influence of temperature and moisture on microbial activity. Decomposition increases exponentially with temperature up to approximately 30°C while the optimum soil water content for microbial respiration is approximately 40% for a silt loam (Waring and Schlesinger, 1985). Both temperature and moisture availability are modified by microsite variables, including topography, shading and soil texture. Seasonal, diurnal, and other fluctuations in soil temperature and moisture can increase overall microbial activity and decomposition (Waring and Schlesinger, 1985).

Meentemeyer (1978) originally proposed using actual evapotranspiration (AET) as an index for litter decomposition. The AET is a useful indicator in that it incorporates the seasonal variation of energy and available soil moisture in an ecosystem and is relatively easily calculated. Comparing litter decay across five (non arid) sites, Meentemeyer (1978) found that AET alone accounted for 51% of the variability in decomposition rates. These AET calculations may also be made on the microsite scale to account for variations in temperature and moisture due to aspect, slope position, elevation, or soil type (Meentemeyer, 1978).
Within sites of similar climate, substrate quality controls litter decomposition to a great extent (Meentemeyer, 1978). Relative to microbial decay processes, substrate quality is defined by: 1) the types of chemical bonds as well as the energy contained within those bonds; 2) the size, shape, and complexity of the molecules composing a substrate; and 3) the concentrations of nutrients found within the substrate (Aber and Melillo, 1991). Lignin concentration is inversely related to decomposition rate and the two factors are highly correlated for a number of sites (Meentemeyer, 1978). Studies have pointed to the importance of N and/or P concentrations relative to C (especially during the early stages of decay) in governing microbial metabolism and hence decomposition (Berg, 1984; Entry and Backman, 1995).

Composting of lignocellulosic material is beginning to receive increased scholarly attention. In general, woody residue is slow to decompose due to its high lignin content, low nutrient concentration, and low surface area:volume ratio (Campbell and Tripepi, 1991; Means et al., 1992). An initial mechanical breakdown of the material hastens decomposition by increasing the surface area available for microbial colonization (N’Dayegamiye and Isfan, 1991). Composting systems require a suitable ratio of C to N (roughly 25:1) in order for decay microorganisms to function at optimum levels (Rodale, 1971); additions of nitrogenous substrates are generally used to compensate for N deficiencies in wood. The activities of mesophyllic and thermophyllic microorganisms greatly accelerate the rate of wood decomposition (N’Dayegamiye and Isfan, 1991); these organisms can be enhanced by piling, watering, and periodically turning substrates (Campbell and Tripepi, 1989).

Successful composting of woody material has been demonstrated by numerous research scientists. Wood shavings and sawdust mixed with cattle manure in a 2:1 ratio by volume was
composted outdoors in Quebec in less than 24 months; the endproduct was determined to be a beneficial soil amendment in terms of crop plant production (N'Dayegamiye and Isfan, 1991). Analysis of composted yard waste (wood, leaves, grass) generated by two firms in Portland, Oregon show improved C:N ratios, moderate pH, high moisture capacity, and suitable levels of all plant nutrients except N (Campbell and Tripepi, 1989).

Composting of woody material without addition of nitrogenous materials is relatively unexplored. Shredded deciduous tree and shrub biomass composted for 90 days has been successfully utilized as a garden soil amendment in Belgium (Savory, 1992). It is unknown whether it is possible to compost the residues of conifer forests which are acidic and relatively resistant to decay.

**Study Goal and Objectives:**
The purpose of this study was to quantitatively and qualitatively evaluate techniques for the utilization of logging residues. The first objective was to assess the usefulness of logging slash, both whole and chipped, in programs designed for revegetating abandoned roads. Various restoration techniques, including mechanical scarification and applications of different forms of logging slash, topsoil, and inorganic fertilizer, and a control of no treatment were compared. The various treatments were evaluated in terms of their effects on soil physical properties and their ability to support vegetation. Working from the hypothesis that slash mulching may be a cost-effective method of enhancing road rehabilitation, I designed this part of the study to identify the minimal levels of mechanical and material inputs necessary for successful amelioration of physical and ecological characteristics.
The second objective of this study was to determine the extent to which different treatments might accelerate decomposition rates of logging slash. Chipped slash containing various proportions of nitrogenous materials was compared to unchipped slash as to temperature, moisture content, and extent of microbial colonization. After one year of decomposition, decomposed slash was sifted and used in a greenhouse growth trial in order to assess its ability to support plant growth.
CHAPTER 3: EXPERIMENTAL DESIGN

Sites, Materials, and Methods

Roads

Road revegetation experiments were carried out during May-October 1997 on 2 contrasting sites in western Montana. One set of plots was established at Lubrecht Experimental Forest (13 North, 15 West, section 11) northeast of Missoula and another in the Elkhorn Mountains on the Helena National Forest (8 N., 2 W., sec. 6). The following summarizes the characteristics of each site and the experimental design used there; a description of response variables and methodologies used at both sites is then provided.

The Lubrecht site lies at 4100 feet elevation and slopes 10% toward the northeast. Mean annual precipitation is approximately 45 cm (Montana Forest and Conservation Experiment Station, 1983). The site is situated on Belt Series colluvium and is mapped as Winkler very gravelly sandy loam, a skeletal mixed mesic Udic Ustochrept (USDA, 1995).

This site occupied a 200 m² section of an approximately 1 km abandoned segment of road bed originally used as State Highway 200 from the 1950s until 1991. Previous to construction topsoil was removed and stockpiled nearby. Both the topsoil and roadbed were determined to be sandy clay loam although the bed had a higher coarse fragment content (Table 2). The subsoil was compacted by construction equipment and an asphalt layer was applied. When the highway was relocated in 1991, the asphalt layer was removed leaving a highly compacted gravelly surface. The site is bordered by a small wetland with the current highway behind to the west. A mature lodgepole pine (*Pinus contorta* Dougl.) stand lies approximately 18 meters to the east.
Due to the compacted, infertile soil and the lack of overstory shading, this site has been slow to revegetate. At the time of plot design, the only plants present onsite were pineapple weed (*Matricaria matricarioides*) and spotted knapweed (*Centaurea maculosa*).

**Table 2. Properties of Lubrecht and Elkhorn soils**

<table>
<thead>
<tr>
<th></th>
<th>% Sand</th>
<th>% Silt</th>
<th>% Clay</th>
<th>Textural Class</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lubrecht-Road</td>
<td>60</td>
<td>18</td>
<td>22</td>
<td>gravelly sandy clay loam</td>
<td>6.8</td>
</tr>
<tr>
<td>Lubrecht-Topsoil</td>
<td>54</td>
<td>24</td>
<td>22</td>
<td>sandy clay loam</td>
<td>6.6</td>
</tr>
<tr>
<td>Elkhorn-Road</td>
<td>68</td>
<td>13</td>
<td>19</td>
<td>sandy loam</td>
<td>5.2</td>
</tr>
</tbody>
</table>

Experimental plots were established during June 1997. A completely randomized design was employed because of the homogeneity of the site in terms of topography, shading, and bed material. An attempt was made to manually remove all existing vegetation and large coarse fragments from the study area prior to treatment. Plots were 1.0 m x 2.0 m separated by 0.25 m buffers of no treatment. Each plot was randomly assigned one of the following treatments:

1. Control (seed only)
2. Lopped slash
3. Lopped slash and fertilizer
4. Chipped slash
5. Chipped slash and fertilizer
6. Topsoil
7. Scarified
8. Scarified and lopped slash
9. Scarified, lopped slash, and fertilizer

Each treatment was replicated 8 times for a total of 72 plots.
Respective plots were scarified using a John Deer tractor; a custom-built ripper attachment with teeth spaced 0.25 m apart scarified plots to a depth of approximately 8 cm. A grass and forb seed mixture was broadcast by hand onto all plots at a rate of 50 kg ha\(^{-1}\); species composition is provided in Table 3. Some plots also received 25 kg ha\(^{-1}\) of manually spread 15-30-15 inorganic fertilizer. Seed and fertilizer were raked to a depth of 2 cm.

Lopped slash amendments consisted of Douglas-fir (\textit{Pseudotsuga menziesii} (Mirb.) Franco.) saplings (< 2.5 cm diameter breast height) from a commercial thinning conducted at Lubrecht during the spring of 1997. Special attention was given to achieving relative uniformity in lopped slash dimensions. Only saplings with moderate amounts of branches and foliage were used. All pieces were trimmed to a length of 2 m. Respective plots received 2 segments of slash totaling 6-8 kg (30-40 Mg ha\(^{-1}\)) and covering 70-80% of the plot surface area. Lopped slash was rotated among plots 2, 6, and 12 weeks after initial preparation to achieve more uniform treatment.

<table>
<thead>
<tr>
<th>Species</th>
<th>%</th>
<th>% Germination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual ryegrass</td>
<td>14.8</td>
<td>98</td>
</tr>
<tr>
<td>Crested wheatgrass- \textit{Agropyron desertorum}</td>
<td>14.2</td>
<td>82</td>
</tr>
<tr>
<td>Intermediate wheatgrass- \textit{Agropyron intermedium}</td>
<td>13.9</td>
<td>85</td>
</tr>
<tr>
<td>Timothy- \textit{Phleum pratense}</td>
<td>14.9</td>
<td>85</td>
</tr>
<tr>
<td>Smooth brome-\textit{Bromus inermis}</td>
<td>13.1</td>
<td>85</td>
</tr>
<tr>
<td>Yellow sweet clover</td>
<td>10.0</td>
<td>70</td>
</tr>
<tr>
<td>Hard fescue-\textit{Festuca ovina duriuscula}</td>
<td>14.9</td>
<td>85</td>
</tr>
</tbody>
</table>

Chipped ponderosa pine (\textit{Pinus ponderosa} Laws.) and Douglas-fir slash were gathered from a commercial thinning near Ninemile Creek west of Missoula. The material contained
needles and wood chips 3-6 cm in length. Chipped slash was applied to the road surface at a rate of 25 Mg ha\(^{-1}\) and raked to an even depth of 1-2 cm with approximately 90% coverage. Salvaged topsoil was applied at a rate of 150 Mg ha\(^{-1}\) and raked to an even depth of approximately 5 cm.

Elkhorn plots were established on a closed logging road approximately 10 miles southeast of Helena during June 1997. This site, at 5400 feet elevation, has an east-facing slope of approximately 5 percent. Average annual precipitation is approximately 37 cm (Western Regional Climate Center). The soil is an acidic sandy loam derived from the granitics of the Boulder Batholith (Table 2). The site sits in an open meadow and receives full sun.

An experimental design employing adjacent units of completely randomized plots was employed at the Elkhorn site. The two units were located at a junction in the road where one fork was mechanically scarified during June 1997 and the other left unscarified; the two units were assumed to possess similar soil characteristics.\(^1\) Each of the following treatments was replicated 8 times.

1. nonscarified, control
2. nonscarified, lopped slash
3. nonscarified, lopped slash and fertilizer
4. nonscarified, chipped slash
5. nonscarified, chipped slash and fertilizer
6. scarified
7. scarified, lopped slash
8. scarified, lopped slash and fertilizer
9. scarified, chipped slash
10. scarified, chipped slash and fertilizer

Elkhorn plots were 1.0 x 0.5 m in dimension. All existing vegetation on the plots was manually removed prior to treatment. A bulldozer blade with teeth (0.6 m spacing) was used to scarify plots to a depth of approximately 12 cm in early June. The seed mixture used at this site
is outlined in Table 4. Seed was manually broadcast at a rate of 60 kg ha$^{-1}$. Chipped slash and fertilizer treatments were identical to those used at Lubrecht. Douglas-fir saplings < 1 inch dbh from a nearby stand were used for the lopped slash treatments. Each plot received 1-2 stems and 70-80% cover; lopped slash was rotated between plots after 3, 6, and 12 weeks.

Table 4. Species composition of seed mix at Elkhorn site.

<table>
<thead>
<tr>
<th>Species</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bluebunch wheatgrass- <em>Agropyron spicatum</em></td>
<td>34</td>
</tr>
<tr>
<td>Slender wheatgrass- <em>Agropyron trachycaulum</em></td>
<td>19</td>
</tr>
<tr>
<td>Smooth brome- <em>Bromus inermis</em></td>
<td>32</td>
</tr>
<tr>
<td>Sheep fescue- <em>Festuca ovina</em></td>
<td>15</td>
</tr>
</tbody>
</table>

At both sites germination success, mid-season plant density, and invasion by nonplanted species were measured by counting the number of shoots (both planted and unplanted) on systematically selected 0.2 m$^2$ quadrats 6 weeks after seeding. Percent cover for the entire plot was also estimated at that time.

After 12 weeks, vegetation from systematically selected 0.2 m$^2$ quadrats was clipped at ground level, oven dried at 60$^\circ$C for 24 hours, separated into planted and unplanted species, and weighed for estimates of aboveground biomass production. The number of planted individuals within the quadrat bearing mature seedheads was also counted as an indicator of potential for future community development. All vegetation response variable were converted to square meter basis for reporting.

Soil physical properties were measured 15-18 weeks after plot establishment in order to assess the effect of treatment on soil compaction and water relations. At the Lubrecht site, a
transect containing 7 points and running parallel to the road 20 m to the east was established for comparison of treatments with relatively undisturbed conditions. The upper 6 cm of surface litter and soil was removed from undisturbed sites previous to measurement in order to eliminate the influence of organic matter. Similarly, at the Elkhorn site, a 7 point transect 8 m west of the road was employed.

Bulk density measurements were taken from treatments 1, 2, 4, 6, 7, and 9 at the Lubrecht site and 1, 2, 6, 7, 8, and 9 in the Elkhorns; bulk densities of adjacent undisturbed soils were measured at both sites. The excavation method as described by Blake and Hartge (1986) was employed. A 13 cm diameter template made of PVC pipe was laid down on the surface of systematically-selected points from respective plots. Soil and coarse fragments were excavated from beneath the template to a depth of approximately 5 cm using a trowel and metal spoon. The volume of each excavated hole was determined by refilling with measured amounts of silica sand (20 grit). The excavated material was collected in individual tins, dried in an oven at 105°C for 72 hours, and weighed in order to calculate bulk density.

Penetrability (i.e. the ease with which an object can be pushed into a soil) was measured on the same plots as bulk density. A hand held penetrometer was used as described by Bradford (1986). This device measures the unconfined compressive strength of a soil; readings are reported in kg cm\(^{-2}\). Readings were systematically collected on four points from the same treatments as for bulk density.

Infiltration capacity tests were conducted on 5 randomly selected plots from the above treatments and undisturbed soils using a single ring infiltrometer as described by Bouwer (1986). A 15 cm diameter metal ring with beveled edges was gently worked into the soil to a depth of 1-
3 cm. Bentonite clay was used to seal the outer edges on plots where sufficient penetration was impossible. One liter of water was poured into the infiltrometer at a rate such that a constant depth of 2.5 cm was maintained. The time required for the entire liter to infiltrate the soil was recorded.3

**Accelerated Decomposition**

In order to characterize the effects of various treatments on slash decay rates, small decomposition sample piles were established at Lubrecht Experimental Forest during October 1996. The piles lie on a mid elevation (approximately 4200 feet) site with no slope and relatively little overstory shading. Encroaching Douglas-fir regeneration (<15 cm basal diameter) remaining from a selection harvest was used in creating the piles. The material was separated into stem (>2 cm diameter) and needle/shoot piles and chipped with a mechanical chipper (average chip length approximately 5 cm). Five 50 kg (fresh weight) piles of each of the following treatments were created:

1. equal parts stem and needle/shoot
2. 2 parts stem and 1 part needle/shoot
3. 2 parts stem and 1 part needle/shoot + 5 kg cow manure
4. unchipped slash

All treatments received 5 kg of local soil as a source of native microbial decay organisms to enhance decomposition. Piles were watered immediately after formation and manually turned the following June in order to accelerate decomposition for purposes of study. Temperatures were measured every month to monitor for initiation of meso- or thermophyllic decomposition.
Decomposition measurements were taken during October of 1997. The number of white-rot fungal colonies over 3 cm in diameter within each pile was counted. Five hundred ml samples were then collected from the center of each pile, weighed, oven dried at 60° C for 24 hours, and reweighed in order to calculate moisture content.

An additional liter of decomposed material was collected from the center of piles of treatment 2 (equal parts stem and needle/shoot). That material was sieved to 10 cm and used in a greenhouse trial to assess the relative ability of that material to support plant growth. Pots were filled with a) 500 ml decomposed slash, b) 250 ml slash and 250 ml soil, or c) 500 ml soil (Table 2). Each treatment was replicated 10 times. All pots initially received 8 seeds of smooth brome (B. inermus) and were watered every 2-3 days. The number of germinated seeds in each pot was recorded after 4 weeks before being thinned to 6 individuals. In late November grass was clipped at base level, air dried for 24 hours, and weighed as a measure of biomass.

Statistical Analyses

All data was analyzed using SPSS 6.1 software (Norusis). Hypotheses were tested at the 0.05 alpha level. All Lubrecht road data was subjected to one way analysis of variance (ANOVA) tests with treatment as the independent variable. The Tukey Honestly Significant Difference post hoc test was used to distinguish between groups at P<0.05 level. Elkhorn data was analyzed using one way ANOVA tests within blocks and independent t-tests between blocks for comparable treatments. Decomposition data was also subjected to ANOVA and Tukey’s test. Where sample data did not appear to meet the necessary assumptions of homogeneity of variance
or normality, the corresponding nonparametric tests, Kruskil-Wallis and Mann Whitney, were performed.

**Hypotheses:**

These experiments were designed to test a number of hypotheses. It was anticipated that mulching with slash would enhance revegetation by maintaining high soil moisture levels relative to unmulched plots; revegetation success was measured by germination and biomass of seeded species in addition to percent cover and seedhead counts. Soil scarification, topsoiling, and fertilization were all expected to encourage revegetation but their relative success could not be predicted. It was unknown whether treatment would affect the establishment and growth of volunteer species. It was further expected that road ripping would improve soil physical properties, specifically bulk density, penetrability, and infiltration capacity, by fracturing the soil and creating macropores. It was unclear whether mulching alone or in concert with scarification would have an effect on physical properties.

It was expected that chipping and piling of slash would accelerate decomposition with regard to fungal colonization and moisture content, by increasing surface area and reducing the exposure of inner pile material to air. It was further anticipated that decomposition would be improved by increases in N content. The ability of one year old decomposed slash to support vegetation relative to a mineral soil was unknown.

Specifically the following hypotheses were tested in this study:

\[ H_0: \text{Surface treatments have no statistically significant effect on revegetation (measured as germination, percent cover, biomass, or seedhead density) of abandoned roads.} \]

\[ H_1: \text{Surface treatments have an effect on revegetation of abandoned roads.} \]
$H_0$: Treatments have no effect on soil physical properties (measured as bulk density, penetrability, or infiltration) of abandoned roads.

$H_1$: Treatments have an effect on soil physical properties of abandoned roads.

$H_0$: Treatments have no effect on decomposition indicators (moisture content, fungal colonization) in small piles after one year.

$H_1$: Treatments have an effect on decomposition indicators.

$H_0$: There is no difference in germination or biomass production due to growth medium.

$H_1$: There is a difference in germination or biomass due to growth medium.
CHAPTER 4. RESULTS

Roads

Revegetation  At the Lubrecht site there was a significant difference in germination of seeded species due to treatment (P < 0.001). All lopped slash treatments supported more individuals than the control (Table 5 and Figure 1); the scarified, lopped and fertilized treatment (#9) contained tenfold more individuals than the control six weeks after site preparation. Percent cover was significantly higher on most lopped slash treatments as well. There were small but significant differences between treatments as to germination of unseeded species (P < 0.01). Treatments 7 and 9 (scarified and scarified/lopped/fertilized) contained significantly less volunteers than treatment 5 (chipped/fertilizer) after 6 weeks.

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td><strong>Germination-6weeks</strong></td>
<td></td>
</tr>
<tr>
<td>Seeded Species (individuals m(^{-2}))</td>
<td>118a</td>
</tr>
<tr>
<td>Unseeded Species (individuals m(^{-2}))</td>
<td>86ab</td>
</tr>
<tr>
<td>Percent Cover</td>
<td>4a</td>
</tr>
</tbody>
</table>

| **Aboveground Biomass-12 weeks** |    |    |    |    |    |    |    |    |    |
| Seeded Species (g m\(^{-2}\)) | 5a | 12abc | 22bc | 10a | 17abc | 19abc | 41cd | 43bcd | 67d |
| Unseeded Species (g m\(^{-2}\)) | 29a | 14a | 25a | 25a | 30a | 31a | 15a | 16a | 20a |
| Seedheads m\(^{-2}\) | 15a | 26a | 51ab | 33ab | 55ab | 40ab | 60abc | 50ab | 90bc |

Treatments with same letter not different at P < 0.05. Treatments: 1-control; 2-lopped slash; 3-lopped slash and fertilizer; 4-chipped slash; 5-chipped slash and fertilizer; 6-topsoil; 7-scarified; 8-scarified and lopped slash; 9-scarified, lopped slash and fertilizer.
At the Elkhorn site, lopped slash also improved germination of seeded species but scarification was a more influential factor (Table 6 and Figure 2). Each scarified treatment supported more seeded individuals than its nonscarified counterpart (all P values < 0.009). Germination of seeded species was negligible on the nonscarified control (mean = 4 individuals); lopped slash mulch with and without fertilizer improved germination on nonscarified plots. Within the scarified unit, both lopped slash treatments significantly improved germination of seeded species over the control. Treatment 8 (scarified/lopped/fertilizer), with a mean of 1001 individuals $m^{-2}$, had the highest overall rate.

Scarification reduced invasion by exotics on most treatments at the Elkhorn site; treatments 3, 4, and 5 supported more volunteers than 8, 9, and 10, respectively (all P values <
0.045). There were no differences in germination of unseeded species within blocks (P values > 0.2877).

![Diagram showing mean plant germination after 6 weeks at Elkhorn site by seeded and unseeded species. Bars equal +/- 1 standard error (n=8). Treatments: 1-control (nonscarified); 2-nonscarified and lopped slash; 3-nonscarified lopped slash and fertilizer; 4-nonscarified chipped slash; 5-non scarified chipped slash and fertilizer; 6-scarified; 7-scarified lopped slash; 8-scarified lopped slash and fertilizer; 9-scarified chipped slash; 10-scarified chipped slash and fertilizer.]

Figure 2. Mean plant germination after 6 weeks at Elkhorn site by seeded and unseeded species. Bars equal +/- 1 standard error (n=8). Treatments: 1-control (nonscarified); 2-nonscarified and lopped slash; 3-nonscarified lopped slash and fertilizer; 4-nonscarified chipped slash; 5-non scarified chipped slash and fertilizer; 6-scarified; 7-scarified lopped slash; 8-scarified lopped slash and fertilizer; 9-scarified chipped slash; 10-scarified chipped slash and fertilizer.

Plant cover after 6 weeks at the Lubrecht site was influenced by treatment (P < 0.005). Lopped slash treatments ranked highest while treatments 2, 8, and 9 were significantly different than the control (Figure 3). At the Elkhorn site, all scarified treatments supported more plant cover than their nonscarified counterparts (P < 0.009). Treatment 8 had more plant cover than treatment 6 while there were no significant differences within the nonscarified plots.
Table 6. Revegetation on nonscarified road revegetation plots at Elkhorn site as influenced by 5 treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination-6 weeks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeded Species</td>
<td>4a</td>
<td>503c</td>
<td>395bc</td>
<td>220ab</td>
<td>261abc</td>
</tr>
<tr>
<td>(individuals m$^{-2}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unseeded Species</td>
<td>31a</td>
<td>15a</td>
<td>19a</td>
<td>33a</td>
<td>25a</td>
</tr>
<tr>
<td>(individuals m$^{-2}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent Cover</td>
<td>0a</td>
<td>3a</td>
<td>3a</td>
<td>1a</td>
<td>2a</td>
</tr>
</tbody>
</table>

Aboveground Biomass-12 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeded Species</td>
<td>0.0a</td>
<td>2.8b</td>
<td>6.1c</td>
<td>2.0ab</td>
<td>5.0bc</td>
</tr>
<tr>
<td>(g m$^{-2}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unseeded Species</td>
<td>14a</td>
<td>6a</td>
<td>3a</td>
<td>5a</td>
<td>9a</td>
</tr>
<tr>
<td>(g m$^{-2}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seedheads m$^{-2}$</td>
<td>0a</td>
<td>0a</td>
<td>0a</td>
<td>0a</td>
<td>0a</td>
</tr>
</tbody>
</table>

Treatments with same letter not statistically different at P < 0.05. Treatments: 1-control; 2-lopped slash; 3-lopped slash and fertilizer; 4-chipped slash; 5-chipped slash and fertilizer.

Table 7. Revegetation on scarified road revegetation plots at Lubrecht site as influenced by 5 treatments.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination-6 weeks</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seeded Species</td>
<td>493a</td>
<td>952c</td>
<td>1001c</td>
<td>853 bc</td>
<td>634ab</td>
</tr>
<tr>
<td>(individuals m$^{-2}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unseeded Species</td>
<td>10a</td>
<td>5a</td>
<td>5a</td>
<td>4a</td>
<td>6a</td>
</tr>
<tr>
<td>(individuals m$^{-2}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent Cover</td>
<td>6a</td>
<td>11ab</td>
<td>16b</td>
<td>12ab</td>
<td>11ab</td>
</tr>
</tbody>
</table>

Aboveground Biomass-12 weeks

<table>
<thead>
<tr>
<th>Treatment</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seeded Species</td>
<td>75a</td>
<td>85a</td>
<td>128b</td>
<td>110ab</td>
<td>105ab</td>
</tr>
<tr>
<td>(g m$^{-2}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unseeded Species</td>
<td>10a</td>
<td>4a</td>
<td>3a</td>
<td>3a</td>
<td>2a</td>
</tr>
<tr>
<td>(g m$^{-2}$)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seedheads m$^{-2}$</td>
<td>20a</td>
<td>11a</td>
<td>25a</td>
<td>21a</td>
<td>26a</td>
</tr>
</tbody>
</table>

Treatments with same letter not statistically different at P < 0.05. Treatments: 6-scarified control; 7-lopped slash; 8-lopped slash and fertilizer; 9-chipped slash; 10-chipped slash and fertilizer.
Figure 3. Mean plant cover after 6 weeks at Lubrecht site. Bars equal +/- 1 standard error (n=8). Treatments: 1-control; 2-lopped slash; 3-lopped slash and fertilizer; 4-chipped slash; 5-chipped slash and fertilizer; 6-topsoil; 7-scarified; 8-scarified and lopped slash; 9-scarified, lopped slash and fertilizer.

Figure 4. Mean plant cover after 6 weeks at Elkhorn site. Bars equal +/- 1 standard error (n=8). Treatments: 1-control; 2-lopped slash; 3-lopped slash and fertilizer; 4-chipped slash; 5-chipped slash and fertilizer; 6-scarified control; 7-scarified lopped slash; 8-scarified lopped slash and fertilizer; 9-scarified chipped slash; 10-scarified chipped slash and fertilizer.
Dry weight aboveground biomass yields of seeded species at the Lubrecht site differed by treatment \((P < 0.00005)\) (Table 5). All scarified treatments (7, 8, and 9) supported at least eightfold more biomass than the control (Figure 5). The lopped/fertilizer treatment carried more aboveground biomass than the control and the chipped treatment. Treatment 9 \((\text{mean} = 67 \text{ g m}^{-2})\) was superior to all other treatments. There were no significant differences in dry weight of unseeded species between treatments \((P \text{ value} = 0.74)\). Treatment 9 contained sixfold more mature seedheads per square meter than the control; both treatments 7 and 9 were significantly superior to treatments 1 and 2.

![Figure 5. Mean dry weight aboveground biomass yield after 12 weeks by seeded and unseeded species at Lubrecht site. Bars equal +/- 1 standard error \((n=8)\). Treatments: 1-control; 2-lopped slash; 3-lopped slash and fertilizer; 4-chipped slash; 5-chipped slash and fertilizer; 6-topsoil; 7-scarified; 8-scarified and lopped slash; 9-scarified, lopped slash and fertilizer](image)

At the Elkhorn site biomass of seeded species was greater on scarified plots (plots 6-10) \((P < 0.002)\) (Figure 6). Within the scarified unit, treatment 8 \((\text{mean} = 128 \text{ g m}^{-2})\) supported more biomass than treatments 6 and 7 \((75 \text{ and } 85 \text{ g m}^{-2} \text{ respectively})\). Within the nonscarified unit
treatments 3 and 5 outperformed the control. With respect to biomass of unseeded species, there were no significant differences within the scarified or nonscarified units (P > 0.33). Treatments 3, 4, and 5 contained more biomass of unseeded species than 8, 9, and 10 respectively. Each scarified treatment contained a greater density of seedheads than its nonscarified counterpart (P < 0.05) and there were no differences between treatments within the scarified and nonscarified blocks (P = 0.12 and 0.11, respectively).

Figure 6. Mean dry weight biomass yield in grams after 12 weeks by seeded and unseeded species at Elkhorn site. Bars equal +/- 1 standard error (n=8). Treatments: 1-control; 2- lopped slash; 3- lopped slash and fertilizer; 4-chipped slash; 5-chipped slash and fertilizer; 6-scarified control; 7-scarified lopped slash; 8-scarified lopped slash and fertilizer; 9-scarified chipped slash; 10-scarified chipped slash and fertilizer.
Soil Physical Properties

Soil bulk density at the Lubrecht site did not vary by treatment 16 weeks after initiation (P = 0.19). Values ranged from 1.8 g cm\(^{-3}\) on the lopped treatment to 2.1 g cm\(^{-3}\) on the control and scarified treatments (Table 8 and Figure 7). The mean value of adjacent undisturbed soils was significantly lower at 1.2 g cm\(^{-3}\) (P < 0.0005). There were significant differences in penetrometer readings due to treatment (P < 0.0005); scarified treatments (7 and 9) were more readily penetrated than other treatments (Figure 8).

Table 8. Soil physical properties for road revegetation plots at Lubrecht site.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>7</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density (g cm(^{-3}))</td>
<td>2.1a</td>
<td>1.8a</td>
<td>1.9a</td>
<td>2.0a</td>
<td>2.1a</td>
<td>2.0a</td>
<td>1.2b</td>
</tr>
<tr>
<td>Penetrability</td>
<td>4.5b</td>
<td>4.5b</td>
<td>4.5b</td>
<td>3.1b</td>
<td>1.7a</td>
<td>1.6a</td>
<td>2.8ab</td>
</tr>
<tr>
<td>Infiltration (minutes/l)</td>
<td>85.6c</td>
<td>65.9c</td>
<td>48.8b</td>
<td>44.5b</td>
<td>4.0a</td>
<td>1.8a</td>
<td>3.9a</td>
</tr>
</tbody>
</table>

Treatments with same letter not statistically different at P < 0.05. Treatments: 1-control; 2-lopped slash; 4-chipped slash; 6-topsoil; 7-scarified; 9-scarified, lopped slash and fertilizer; 10-undisturbed.

Infiltration rates at the Lubrecht site were highly variable (Figure 9). Rates on scarified treatments (7 and 9) were not different from the undisturbed soils but were significantly greater than all other treatments. Topsoil and chipped treatments (6 and 4) had greater rates than the lopped treatment and control. The control plots were relatively impervious to water requiring over 80 minutes on average to absorb 1 liter of water.
Figure 7. Mean soil bulk density after 16 weeks at Lubrecht site. Bars equal +/- 1 standard error (n=5).

Figure 8. Mean soil penetrability after 16 weeks at Lubrecht site. Bars equal +/- 1 standard error (n=5).
Figure 9. Mean infiltration rate (minutes/ liter) at Lubrecht site. Bars equal +/- 1 standard error (n=5).
Treatments: 1-control; 2-lobbed slash; 4-chipped slash; 6-topsoil; 7-scarified; 9-scarified, lopped
slash and fertilizer; 10-undisturbed.

At the Elkhorn site, soil bulk densities varied significantly by treatment after 15 weeks (P
value < 0.005). Densities were lower on scarified treatments (6, 7, 8, and 9) than on nonscarified
(1 and 2) (Table 9 and Figure 10). The scarified/lopped and scarified lopped/fertilizer treatments
had the lowest mean bulk densities (0.9 and 0.8 g cm\(^{-3}\) respectively) and were not different from
the undisturbed soils (P value = 0.51). Penetrability followed a similar trend: all scarified
treatments and the undisturbed soil were more readily penetrated than nonscarified (Figure 11).

Infiltration rates were again greatest on the scarified treatments (Figure 12). There was
no difference in rates between scarified treatments and the undisturbed soils (P values > 0.207).
Both nonscarified treatments required an average of more than 70 minutes to absorb one liter of
water.
Table 9. Soil physical properties for road revegetation plots at Elkhorn site.

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Bulk density</td>
<td>1.7c</td>
</tr>
<tr>
<td>(g cm⁻³)</td>
<td></td>
</tr>
<tr>
<td>Penetrability</td>
<td>3.6b</td>
</tr>
<tr>
<td></td>
<td>(minutes/1)</td>
</tr>
<tr>
<td>Infiltration</td>
<td>71.8b</td>
</tr>
</tbody>
</table>

Treatments with same letter not statistically different at P < 0.05. Treatments: 1-control; 2-lopped slash; 6-scarified control; 7-scarified lopped slash; 8-scarified lopped slash and fertilizer; 9-scarified chipped slash; 11-undisturbed.

Figure 10. Mean soil bulk density after 15 weeks at Elkhorn site. Bars equal +/- 1 standard error (n=5). Treatments: 1-control; 2-lopped slash; 6-scarified control; 7-scarified lopped slash; 8-scarified lopped slash and fertilizer; 9-scarified chipped slash; 11-undisturbed.
Figure 11. Mean soil penetrability after 15 weeks at Elkhorn site. Bars equal +/- 1 standard error (n=5).

Figure 12. Mean infiltration rate (minutes/1 liter) at Elkhorn site. Bars equal +/- 1 standard error (n=5).
Accelerated Decomposition

After one year the material from all chipped piles appeared partially decomposed. Needles in the chipped piles were black and greasy in appearance while the majority of needles in the lopped piles were still green and attached to branches. The moisture content of chipped treatments was significantly higher than lopped (P < 0.005); material from the center of chipped piles all averaged greater than 135% moisture in October while the lopped slash was 50%.

Fungal colonization by white rot species was significantly greater in chipped treatments without manure than in unchipped piles where no colonies were found (P value = 0.007). Chipped pile temperatures never exceeded ambient air temperatures.

Table 10. Decomposition indicators by treatment.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Percent moisture</th>
<th>Fungal Colonies per pile</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>152b</td>
<td>4ab</td>
</tr>
<tr>
<td>2</td>
<td>138b</td>
<td>6b</td>
</tr>
<tr>
<td>3</td>
<td>157b</td>
<td>5b</td>
</tr>
<tr>
<td>4</td>
<td>50a</td>
<td>0a</td>
</tr>
</tbody>
</table>

Values with same letter are not different at P < 0.05. Treatments: 1-equal parts stem and foliage plus manure; 2-equal parts stem and foliage; 3-2 parts stem to 1part foliage; 4-unchipped

In the greenhouse experiment, germination of grass seed was affected by the medium in which it was grown (P = 0.007) (Table 11 and Figure 13). The number of germinated seeds in pure soil was not significantly different from that in soil/slash mixture or pure slash. There were no differences between dry weight yields from various growth media after 8 weeks (P = 0.20) (Figure 14).
Table 11. Vegetation response to various growth media.

<table>
<thead>
<tr>
<th>Growth Medium</th>
<th>Soil</th>
<th>Soil/Slash</th>
<th>Slash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germination</td>
<td>5.1ab</td>
<td>6.0b</td>
<td>4.2a</td>
</tr>
<tr>
<td>(plants pot⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biomass</td>
<td>0.0066a</td>
<td>0.0095a</td>
<td>0.0089a</td>
</tr>
<tr>
<td>(g pot⁻¹)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Values with same letter are not different at P < 0.05.

Figure 13. Mean germination rates by growth medium. Bars equal +/- 1 standard error (n=11).

Figure 14. Mean aboveground biomass yield (dry weight) by growth medium. Bars equal +/- 1 standard error (n=11).
CHAPTER 5. DISCUSSION

Roads

Of the treatments studied here, scarification was most effective in rehabilitating abandoned roads. All measured physical properties were improved on ripped plots at the Elkhorn site while penetrability and infiltration showed significant improvements due to scarification at Lubrecht. As expected, the mechanical fracturing of soil increased porosity and reduced strength thereby lowering density and resistance to penetration. The Lubrecht site did not show improvement in bulk density due to scarification after 3 months; a lack of fracturing due to the relatively high coarse fragment content or post-scarification processes such as soil settling or surface sealing may account for this discrepancy.

Ripping creates large water-conducting channels and thereby accelerates water infiltration which is of particular significance in erosion control (Luce, 1997). The scarification techniques used in this study (i.e. ripping to depths of 8-12 cm) were sufficient to improve infiltration rates to levels equal to undisturbed soils on both sites after 3 months. Infiltration rates on all scarified plots appear likely to exceed 11.25 cm hr$^{-1}$, the approximate 100 year-10 minute rainfall events for both Missoula and Helena (U.S. Weather Bureau TP-25). Scarification then provides an important degree of protection against overland flow and erosion during high intensity rainfall episodes.

It is difficult to predict the effect of scarification on soil physical properties into future years. Surface sealing (due to the filling of macropores with transported fine particles) and soil settlement occur to some extent on all scarified soils (Gifford, 1975). The surfaces of a number of roads in Idaho forests returned to original bulk densities and poor infiltration capacities one year after scarification (Luce, 1997). Conversely, by increasing soil moisture content during the
first year, scarification can enhance the fracturing of soil clods via frost action and thereby ensure continued reductions in bulk density (McNabb, 1994). The establishment of vigorous plant communities on tilled soils may maintain improvements to physical properties by protecting soils from rain drop impact and supplying organic matter.

Scarified treatments produced the highest average aboveground biomass of seeded species after a single growing season at both the Lubrecht and Elkhorn sites. Seedhead density, an indicator of plant community vigor, was also greatest on scarified plots at both sites. Scarification creates a suitable seedbed by improving soil moisture levels, reducing soil strength for root penetration, and ensuring adequate seed burial (Veihmeyer and Hendrickson, 1948; Cotts et al., 1991). The benefits of ripping on revegetation were especially obvious at the Elkhorn site where scarified plants produced thick healthy grass communities while nonscarified plots carried very little vegetation. Intense early summer rainstorms appeared to have transported seed and soil from the nonscarified plots downslope. On both sites, grasses preferentially occupied the ripped trenches where the maximum benefits in terms of water relations, soil strength, and seed burial are realized. Narrow spacing between the teeth of rippers or subsoilers may be advantageous.

Scarification also appears to affect invasion by weedy species. At the Lubrecht site germination of unplanted species was generally lower on scarified plots although there was no statistical difference in biomass after 12 weeks. At the Elkhorn site germination and biomass of unseeded species were lower on scarified treatments. Seedbed characteristics are known to have an effect on plant community composition by preferentially enhancing the competitive abilities of some species (Schuman et al, 1985; Maynard and Hill, 1992). In this case, scarification
discouraged invasion by volunteers probably by improving soil water relations and thereby improving the growth of seeded species.

Mulching with lopped slash alone was not as effective as scarification but did generally produce significant improvements in growth of seeded plants over control plots. Lopped slash treatments ranked high in germination levels at both sites after 6 weeks. As with other mulches, branches shades the soil surface and thereby results in relatively low evaporative demand and possibly increased soil moisture levels (Hopkins, 1984). Mulching with branches also produces a variety of microsites with respect to shading for plant growth.

After 12 weeks lopped slash treatments produced more modest results: biomass of seeded species was not significantly greater than the control at Lubrecht and only slightly better at the Elkhorn site. Similarly, seedhead density was not increased at either site by branch mulching alone. Without scarification, the high soil strength likely restricts root penetration while soil moisture recharge may be insufficient for plant growth later in the season. Cotts et al. (1991) suggest that mulch may inhibit soil moisture recharge during low intensity and low duration rainfall events common in the Rocky Mountain region via interception and subsequent evaporation.

Mulching with chipped slash did not in general produce favorable results. Neither seeded species biomass nor seedhead density was increased by chip mulch alone at either site. Germination of seeded species was improved by chip mulching at the Elkhorn site but only in conjunction with scarification. Due to their light color wood chips are highly reflective. Lower radiation loads at the soil surface may increase soil moisture levels, however the highly reflective
chips would also create a fairly harsh growing environment above the surface. Mulching with chips or whole branches did not effect invasion by exotics.

Mulching in conjunction with scarification had a number of favorable results. At the Lubrecht site, the scarified/lopped treatments exceeded other treatments in germination, biomass, and seedhead density. Treatment 8 (scarified/lopped) contained eightfold more dry weight of seeded species and threefold greater seedhead density than the control. Vegetation responses on the scarified/lopped plots however were not significantly improved over simply scarified plots. Similarly at the Elkhorn site, scarified/lopped and scarified/chipped plots were not significantly better than scarified alone in terms of vegetation.

Lopped/scarified treatments showed the greatest improvements in soil physical properties after 4 months at the Elkhorn site. Mulch can be important in protecting freshly tilled soil from rainfall impact, splash erosion, and subsequent surface sealing of water-transmitting pores (Onstad et al., 1984; Luce, 1997) Luce (1997) also reports variable improvements to infiltration rates on ripped and mulched roads; depending on soil texture and coarse fragment content, mulching can prolong the physical improvements generated by scarification through some high intensity rain events.

The addition of inorganic fertilizer had modest effects on growth of seeded species in most cases. On nonscarified treatments at both sites, fertilization improved biomass production on mulched treatments relative to the control; however biomass was not significantly greater than those treatments receiving only mulch except in one case. On scarified plots at both sites, applications of fertilizer increased biomass yields on lopped but not chipped mulch plots. There were no increases in seedhead density as a result of fertilization. It appears that the primary
limitation on plant growth at both sites was water availability. Where scarification and mulching sufficiently increased plant available water, the benefits of fertilization were discernible. Nutrient deficiencies were expected at both sites due to a lack of organic matter as a result of topsoil removal and erosion. Supplemental N, P and K in inorganic forms appear to have helped overcome those deficiencies; additions of humified organic matter might also be used to supply those nutrients.

At both sites, the scarified/lopped slash/fertilizer treatments produced the greatest dry weight of seeded species and seedhead density. That combination of treatments appears to have best addressed the physical and chemical factors limiting plant growth at these sites. As previously discussed, scarified and mulched plots showed the greatest improvements in soil physical properties except in the case of bulk density at the Lubrecht site. The combination of scarification, lopped slash mulching, and fertilization constitutes the most effective treatment studied here and is recommended in situations where funding is not unduly limited or the probability of project failure must be minimized.

In this study applications of topsoil did not prove to be effective in promoting revegetation or improving soil physical properties. Vegetation response variables on topsoiled plots were not significantly different from the control. Bulk density and penetrability were not improved by topsoiling although infiltration was moderately accelerated. It was expected that dressing with relatively fertile, uncompacted soil would provide an improved substrate for plant growth. However, applications of topsoil to only 5 cm depths without scarification were apparently not enough overcome the poor water relations associated with the compacted road bed.
These results disagree with other investigations where topsoiling was a beneficial technique in mine and road reclamation in terms of soil properties and plant community establishment (Wright and Blaser, 1981; Schuman et al., 1985). Unlike in other studies though, topsoil was applied at minimal rates and not in conjunction with other treatments in accordance with the objective to identify minimal inputs required to successfully reclaim roads. The effectiveness of topsoil was studied at only one site and should not be generalized to other sites especially those marked by less compaction. However the high costs associated with purchasing, hauling, and spreading of topsoil render it unsuitable for many forest road reclamation projects.

Other potential applications for these treatments exist in the Rocky Mountain region. Scarification and mulching techniques would presumably benefit other compacted sites in forests including skid trails and landings. Slash mulching could also be used in conjunction with complete road obliteration where excavated material is exposed to accelerated erosion (Moll, 1996). Finally slash could be used as an inexpensive mulch and source of organic matter in abandoned mine reclamation.

The use of logging slash in road rehabilitation has other potential benefits not quantified in this study. After 1-2 years needles drop to the soil surface and become a source of soil organic matter for the near future. Thicker branches are slower to decompose and may serve many of the roles of coarse woody debris in forest ecosystems, including functioning as nurse logs or sites for ectomycorrhizal formation or N gas fixation (Graham et al., 1994). The application of lopped slash creates structural diversity along the soil surface that may serve as insect and animal habitat. Finally, mulching with large branches and stems may protect newly-reclaimed sites by discouraging access and use by vehicles and hikers.
Logging residues have minimal market value; the principal costs associated with slash mulching then are transportation and application. Fortunately access to logging residues is greatly expedited by new logging technology. Timber harvest in the northern Rockies is increasingly dominated by feller-bunchers which haul whole trees to landings for delimming. Because it is concentrated at the landings, slash could be transferred to trucks with relative ease using log loaders. Dump trucks could haul the material to reclamation sites where it might be spread manually or with an excavator.

The results of this study suggest that the use of whole-branch logging slash in conjunction with scarification is warranted in the rehabilitation of abandoned roads. Furthermore, on sites where scarification is cost-prohibitive, mulching with lopped slash constitutes a beneficial alternative. The lack of market value and physical proximity to forest roads make logging slash an advantageous material for road rehabilitation; road rehabilitation in turn offers an opportunity for efficient use of the carbon and nutrients contained in logging residues.

**Accelerated Decomposition**

Chipping and piling clearly conserved moisture in the inner pile where slash was sheltered from contact with air and solar radiation. Such treatment would presumably extend the period of time during which decomposing organisms are active into normally moisture-limited summer months (Spaulding and Hansbrough, 1944). Maintaining moisture content near optimum levels also enhances the marginal rate of decomposition (Wagener and Offord, 1972).
Fungal colonization was enhanced by chipping and piling of material. Chipping initiates decomposition by rupturing cells while increasing the surface area available for colonization (Aber and Melillo, 1991). N'Dayegamiye and Isfan (1991) observed increased rates of composting with finer grinds of woody material. Additional disintegration of logging residues by tubgrinders would presumably further enhance decomposition.

Because pile temperatures never warmed beyond ambient air temperatures, it can be assumed that decomposition by mesophyllic or thermophyllic organisms was not initiated in the first 12 months. The high lignin content relative to N concentration of the material is a likely explanation. It was observed that internal chipped piles did not freeze as early in the winter as did the outer edges or the lopped slash; composting techniques then presumably extend the duration of decomposition.

Manure was added to one set of piles in order to test whether an additional N source would enhance decomposition in the short term. Fungal colonization was not greater in manure piles nor was there visual evidence of improved decomposition. Although decomposition of most substrates increases with N availability, nutrient concentration and forest decomposers is still not well defined; additions of N to lignin-containing substrates have been shown to inhibit decomposition by white-rot fungi (Entry and Backman, 1995).

The results of this experiment indicate that decomposition of forest residues with high foliage content can be enhanced by composting techniques. Although not definitively studied here, chipping, piling, and inoculating slash with local decomposers appears to have increased its rate of decomposition at least in the first year. The amount of time required for complete decomposition and humification of slash using these techniques is unknown and deserves long-
term study. Furthermore, the data indicates that after one year, it is possible to generate compost from logging slash that is not harmful to plant growth.

A practical approach to slash composting must address several key prerequisites. An initial mechanical breakdown of the material is needed to increase surface area for microbial degradation. Depending on regional demand for pulpwood, many large logging firms currently use chippers or tub grinders in their operations in order to utilize otherwise nonmerchantable wood. If composting of slash is desired, timber harvest contracts could specify that a certain percentage of fine material be ground and left to decompose onsite or transported immediately to other locations. This may prove to be an economically feasible approach to the handling of large quantities of slash.

Accelerated decomposition of woody material also requires suitable moisture and temperature regimes. These presumably are available at mid to upper elevations on all but south aspects in the Intermountain West. Shading preserves moisture content in slash; locating piles near or under tree canopies would enhance decay (Spaulding and Hansbrough, 1944). Larger piles have less surface area per unit volume and thus would better conserve moisture and heat.

Slash composting could serve as a source of decomposed organic matter for forest managers in a variety of applications. The material could be used as a mulch or soil amendment in abandoned road revegetation. Abandoned mines are other degraded sites commonly found in the northern Rocky Mountain region. Treatment of both acidic and saline mine tailings with organic amendments is known to enhance revegetation success and potentially reduce the availability of toxic metals (Schuman and Belden, 1991; Sopper, 1992). A primary advantage of
using logging slash in such reclamation projects is the physical proximity of abandoned roads and mines to forest stands.

Decomposed logging residues could also be returned to the stands of their origin. Although land spreading of organic matter in forests is virtually unheard of, the benefits of that material to tree and seedling growth has been well documented. The removal of organic matter from forest soils reduces nutrient holding capacity and overall fertility (Clayton and Kennedy, 1985). Soil water holding capacity and formation of ectomycorrhizal associations increase with organic matter content up to 45% by volume (Harvey et al., 1981; Harvey, 1982). Douglas-fir seedling vigor, including bud extension, N and P uptake, and total biomass, improves with increasing soil organic matter content (Graham et al., 1989; Page-Dumroese et al., 1990). Enhancing the soil organic matter content via land spreading of slash compost may prove particularly valuable on droughty or nutrient-limited sites (Harvey et al., 1981; Kimmins, 1987).

**Conclusion**

Logging residues are an often neglected source of organic matter in the northern Rocky Mountains. Utilization of that material for small log products, pulp, and hog fuel has greatly increased since the 1960s (Benson and Schlieter, 1980). This paper has summarized research on two techniques for further usage. Other techniques surely exist. For example, many National Forests have begun to make slash piles available for firewood gatherers. Discovering ecologically and economically sound applications for logging residues may well be one of the many challenges facing future forest managers.
Ruth and Harris (1975) define logging residues as “the leftovers—the organic material without enough value to justify its removal” (p.4). To date, logging slash has indeed been perceived as a waste product whose disposal requires expenditure of human resources and results in net losses of organic matter and diminished air quality. However, with increasing demand for organic amendments and continued scarcity of sources in the northern Rocky Mountain region, alternative management techniques such as those studied here may shift the perception of logging slash to one of valued resource.
Footnotes

1. The assumption of equality between the side-by-side blocks is of course critical to the design of this experiment. Both spurs were well compacted; pretreatment penetrometer readings were similar for both. There was no apparent visual difference in texture, degree of erosion, or organic matter content.

2. Grass and forb seed mixture for the Lubrecht site was furnished by the Missoula Ranger District of the Lolo National Forest. Reclamation projects on this District typically involve nonnative species due to the lower costs of seed (S. Hegman, pers. comm.). For the Elkhorn site, a seed mixture of native species was provided by the Helena District of the Helena National Forest at the request of local managers. Different seed mixtures were used as a matter of practicality; however the difference tends to reinforce the contrasting nature of the two trials. By utilizing different species as well as different soils, climates, and degrees of compaction, I could hope to better assess the utility of slash in road revegetation programs in general.

3. Infiltration capacities are often reported as rates (e.g. cm hr⁻¹). One liter of water fills a 15 cm diameter infiltrometer to a depth of 5.66 cm. Infiltration rates can be estimated using that number and a reading in minutes but with less accuracy for readings more or less than one hour.

4. Toads were found in lopped slash plots exclusively at the Lubrecht site during the 6 and 12 week data collection periods. Conditions were hot and dry on both occasions and branches apparently afforded adequate shelter.
Literature Cited:


